SCIENTIFIC PREPARATIONS FOR AEOLUS AND AEOLUS FOLLOW-ON

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ABSTRACT

In spring 2010 the ESA Core Explorer Atmospheric Dynamics Mission, ADM-Aeolus is due for launch. Scientific preparations are being made in the area of campaigns, Cal/Val, and the development of an End-to-End simulator, E2S, L1 and L2 wind profile processor. In this manuscript the focus will be on Aeolus performance in relation to atmospheric heterogeneities. Both in terms of processing and in terms of the distribution of vertical range gates (vertical processing levels) the characteristics of the atmosphere play an important role. High-resolution radiosondes, space lidar (CALIPSO), ECMWF model data and ground based measurement data sets are collocated to yield the combined optical and dynamical properties of the atmosphere that are relevant for Aeolus. The Aeolus mission will last three years. Studies have been conducted to develop user requirements for an Aeolus follow-on mission. From these studies wind profile coverage appears important rather than the measurement perspective in the extratropics, while in the tropics both the zonal and the meridional perspectives are important as well as wind profile coverage. A complement of a side- and back-looking Aeolus type instrument would fulfil the stated requirements.

1. INTRODUCTION

The Aeolus mission and the current status of the wind ground processor are published in this issue, resp. by Ingmann and Straume and Tan et al.. The atmospheric wind will be measured by a single payload onboard the Aeolus satellite, the Atmospheric LAser Doppler INstrument (ALADIN). This is a direct detection High Spectral Resolution Lidar (HSRL), operating in the ultra-violet spectral region. Its laser emits a short but powerful laser pulse toward the atmosphere, from which a small portion is scattered back by air molecules and cloud and aerosol particles. A telescope collects the backscattered light and directs it to optical receivers which measure the Doppler shift of the received signal. The ALADIN Doppler Wind Lidar (DWL) detects the backscattered light from Mie (particle backscatter) and Rayleigh (molecular backscatter) separately, allowing for accurate particle and molecule backscatter and extinction products. The HSRL is, however, sensitive to cross-talk contamination (Tan et al., 2008) especially in the case of strong Mie-backscatter (e.g. from cirrus clouds). The cross-talk will be removed with care, with the help of appropriate instrument calibration. This cross-talk correction is dependent on a perfect vertical matching (one-to-one, one-to-two, etc. ratio of the bin thicknesses) of the Mie and Rayleigh sampling bins. A main limitation in the vertical bins is its number; only 24 Mie and 24 Rayleigh receiver bins are available. Moreover, the vertical bin size may be multiples of 250 m, but at maximum 2000 m. With these given constraints, it is thus relevant to investigate which vertical sampling schemes provide most wind information in which geographical region.

ADM-Aeolus will look into a both horizontally and vertically heterogeneous atmosphere, exhibiting aerosol stratification and moving clouds, complicating the interpretation and usefulness of the Aeolus observations. We discuss below the atmospheric wind heterogeneity, the atmospheric optical heterogeneity and the implications for Aeolus vertical measurement positioning.

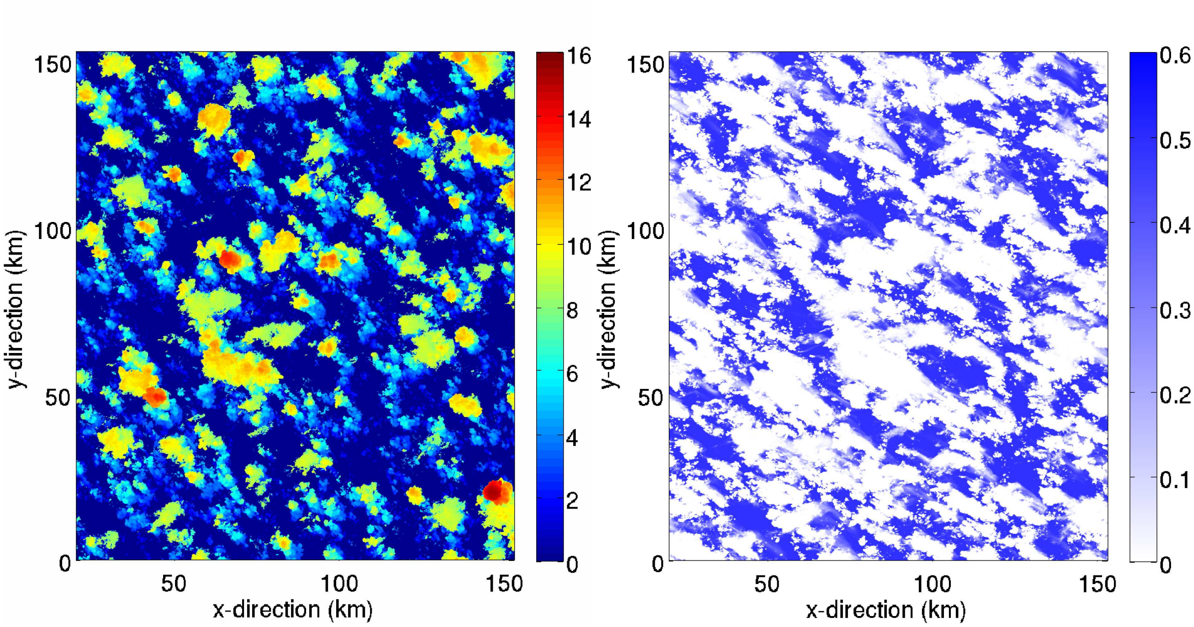

Figure 1. Top view of cloud top height in km (left) and transmission (right) at 37.5 degrees incidence angle for the SAM with domain 154kmx154km sampled on a 100m grid as provided by Khairoutdinov and Randall (2006). The tropical scene at 14:00 LST shows maturing convective clouds (with no cirrus).

2. MODELLED ATMOSPHERIC HETEROGENEITY

The maximum horizontal wind change over one observation (50 km) is about 50 m/s. The wind velocities can reach maxima of about 125 m/s at tropopause level (polar-front and subtropical jets), and 140 m/s above 25 km (polar stratospheric jets). The jets are important for the determination of the tropospheric and stratospheric dynamics. The largest vertical wind shears occur throughout the baroclinic mid-latitude atmosphere and around the tropopause. Here, vertical wind shears exceeding 50 m/s per km can occur. These sharp gradients are important for the atmospheric dynamics, and furthermore pose a challenge for data assimilation due to the associated large spatial wind variability. The jets are typically vertically narrow. ADM-Aeolus may therefore occasionally not be able to sample the jets because of the proposed 1 km vertical resolution at the tropopause. Above 15 km and in the tropics, the maximum wind shear is much smaller and such problems are less likely to occur. The mean wind shear in the troposphere is about 4 m/s per km height, which is an order of magnitude smaller than the maximum values.

In the case where shear layers are associated with cloud or aerosol stratification, particularly large spatial representativeness errors will occur. In the case of an optically thick cloud or aerosol layer in e.g. the lower part of a range-gate, the Rayleigh return signal will originate from the upper part above the cloud, whereas the Mie signal will originate from the lower part. Thus the Rayleigh and Mie channels may observe different wind velocities in the case of wind shear. The Rayleigh and Mie returns will both exhibit height assignment errors but of a different size. The Mie signal height may vary considerably with an average RMS error of 100 m within a 1 km vertical range bin. The respective Rayleigh average RMS height assignment error is 25 m and less relevant. However, for cases where a cloud deck or optically thick aerosol layer splits a range gate, larger height assignment errors will occur occasionally.

The combination of the common tropospheric maximum wind shear of 50 m/s per km and the 100 m RMS Mie height assignment error clearly results in unacceptable wind errors of 5 m/s RMS. These types of error can be quite detrimental in Numerical Weather Prediction (NWP) analyses and forecasts. Measures to recognise such scenes should be put in place, so that these can be rejected or controlled.

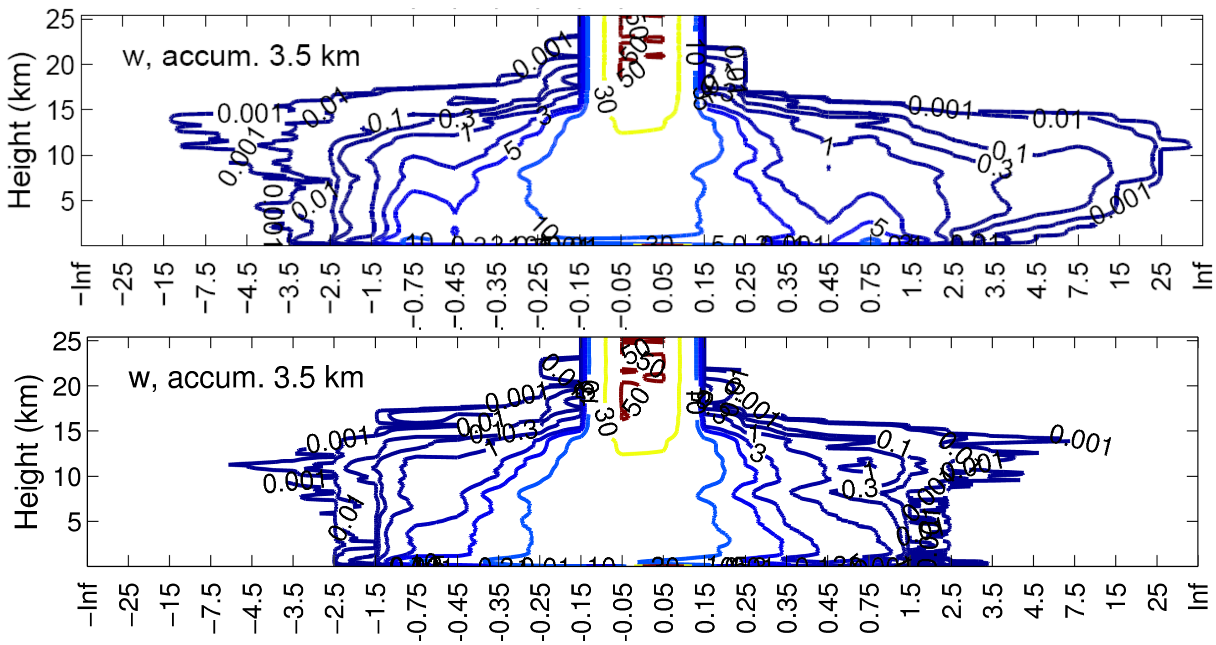

Figure 2. Top: relative occurrence of vertical winds (horizontal axis in m/s) at different heights (vertical axis). Bottom: as top, but only for those winds that may be retrieved by Aeolus with sufficient optical signal (no cloud obscuration). Note that the horizontal scale is irregular.

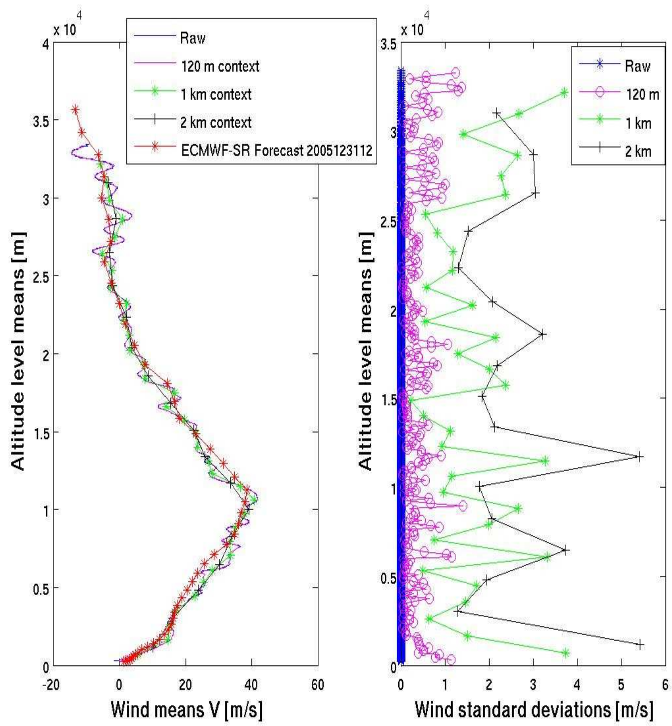

Figure 3. Left: Example radiosonde ascent in high resolution representation (raw; 30m) and with running averages over 120m, 1km and 2km. For reference the ECMWF short range forecast is given at the same time and (ground) location. On the right the wind departure (SD) from the mean wind over vertical ranges of 120m, 1km and 2km is given at different height levels. Clearly, the larger the range, the more wind variability is contained in it. Note that the smoothness of the ECMWF profile resembles best the 2km averaging kernel, implying a lack of wind variability in the vertical of 2-3 m/s as indicated by the black line.

In Figure 1 a scene simulated with a Cloud Resolving Model (SAM) is shown as cloud top height from the top and cloud transmission at the local Aeolus incidence angle of 37.5 degrees at 13:30 LST (Local Solar Time) in the tropics.

Figure 2 shows that vertical winds may be as high as 25 m/s. At such large vertical speeds, thick clouds form quickly and the ADM-Aeolus measurement system will generally not experience such strong vertical winds in the atmosphere, but at most 1 or 2 m/s locally. Therefore, averaged over 50 km stretches, we do not expect a strong aliasing effect of the vertical wind into the measured Line-Of-Sight, LOS, wind. We may thus generally safely assume that Aeolus measures a component of just the horizontal wind. However, in some tropical areas, vertical winds higher than 1 m/s may be seen occasionally by Aeolus and QC measures should be put in place.

3. VERTICAL VARIABILITY OF THE HORIZONTAL WIND, CLOUDS AND AEROSOL

Figure 3 shows that the variability of the horizontal wind is large in the vertical for a typical high-resolution radiosonde ascent at 90.6W 41.6N on 1 January 0 UTC 2006. What is the effect of this variability on the Aeolus measurements? From Figure 3 we also note that ECMWF fields are smooth as compared to the high-resolution radiosonde and typically represent a vertical resolution of about 2 km in the vertical. Within 2 km context the variability of the horizontal wind is 2-3 m/s. Within Aeolus resolution (1 km) the vertical variability of the horizontal wind is about 1 m/s. We also note that the profiles at 30m and 120m context are very similar, indicating low random noise in the radiosonde.

Not many collocations of optical and dynamical measurement data exist. In order to build a set of climatologically representative scenes for ADM-Aeolus, we use available CALIOP data. The space-borne CALIPSO mission successfully acquires space-borne lidar data from the CALIOP instrument for more than a year, thereby covering all seasons. We collocate CALIOP data for all seasons with NWP model fields from ECMWF in order to acquire collocated atmospheric optical and dynamical data. We here focus on the variability of the horizontal wind in association with the optical variability.

We transform CALIOP data to molecular and particle backscatter and extinction data at ADM-Aeolus optical wavelength (355 nm) and horizontal resolution. The Aeolus vertical resolution is oversampled at 125 m. The latter is done in order to be able to study the effect of vertical wind gradients in the horizontal wind in combination with the optical heterogeneities. Since we collocate with ECMWF fields that are rather smooth, the resulting wind biases would be strongly underestimated. We just show here the biases in height assignment.

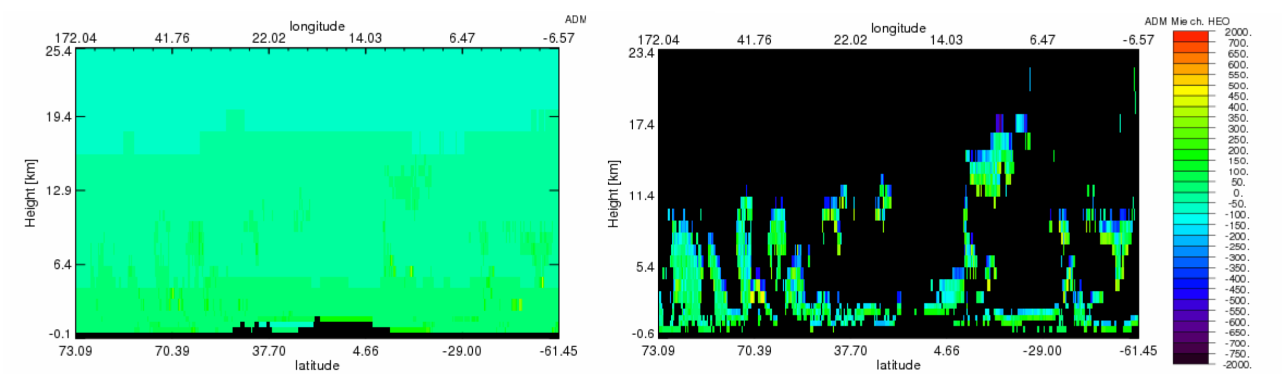

Figure 4. Signal-weighted height minus geometrical range gate height for the Rayleigh channel (left) and the Mie detection channel (right).

Figure 4 shows for a particular cloudy scene the signal-weighted height minus the geometrical range gate height. Errors in the height assignment due to the integration over a range gate are negligible for the Rayleigh channel, but substantial for the Mie channel, i.e., from +500m to -700m. We also note that in the lower troposphere negative and positive height differences occasionally occur in adjacent range gates. This means that vertical gradients in the horizontal wind will be wrongly estimated by the Aeolus measurements. QC techniques need to be developed to avoid such unrepresentative winds.

4. ADM-AEOLUS FOLLOW-ON

In the ESA project PIEW - Prediction Improvement of Extreme Weather – the added value of space-borne DWLs in NWP systems to enhance the predictive skill of high-impact weather systems was assessed. The DWL coverage and quality needed to capture rapidly-evolving sensitive structures, which are otherwise not observed, was investigated. This provided capability requirements for ADM follow-on systems.

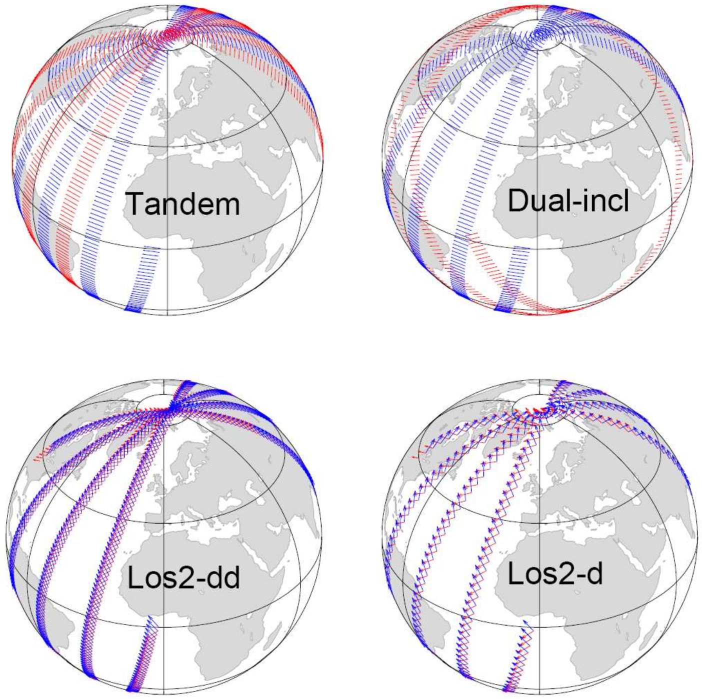

Figure 5. PIEW follow-on scenarios:

- **Tandem: twice the Aeolus coverage with interleaving tracks (orbit phase shift);**
- **Dual inclination: An Aeolus copy and in addition a more inclined DWL for increased storm track coverage and multiple LOS perspectives;**
- **LOS2-dd: A double Aeolus information content by providing the wind vector at each location;**
- **LOS2-d: Aeolus information content by providing the full wind at half the number of locations.**

Verification 00 Z 28 Dec 1999 +54-h forecasts	# Members of 50 speed > 10 Bft or PMSL < 980 hPa
NoDwl	5
DWL	15
Pseudo-truth	38

Table 1. Verification of the 84-hour cycled SOSE experiment on the Ensemble Prediction System two-day forecast of the extreme storm "Martin" according to common storm detection criteria.

In the extratropics extreme forecast failures were studied and the potential complementary value of the DWL scenarios (Figure 5) was assessed. A new technique was employed, called Sensitivity Observing System Experiment (SOSE; see Marseille et al., 2008a-c).

Table 1 shows an illustration of the tandem DWL impact on superstorm "Martin" which left a devastating track in Western Europe on 28 December 1999. Despite the improvements in NWP in the last decade, Martin remains difficult to predict. One of the reasons for this may lie in the lack of observational data in the source region. To test this, we ran SOSE for three cases. The NoDWL case uses all real observations available at the time, but uses a recent version of the ECMWF Integrated Forecasting System, IFS. The "Pseudo-truth" case uses information from the future (two days ahead) in each 12-hour cycle, projected back on the analysis time through the ECMWF model adjoint. In the DWL case, the pseudo-truth is sampled by tandem Aeolus-

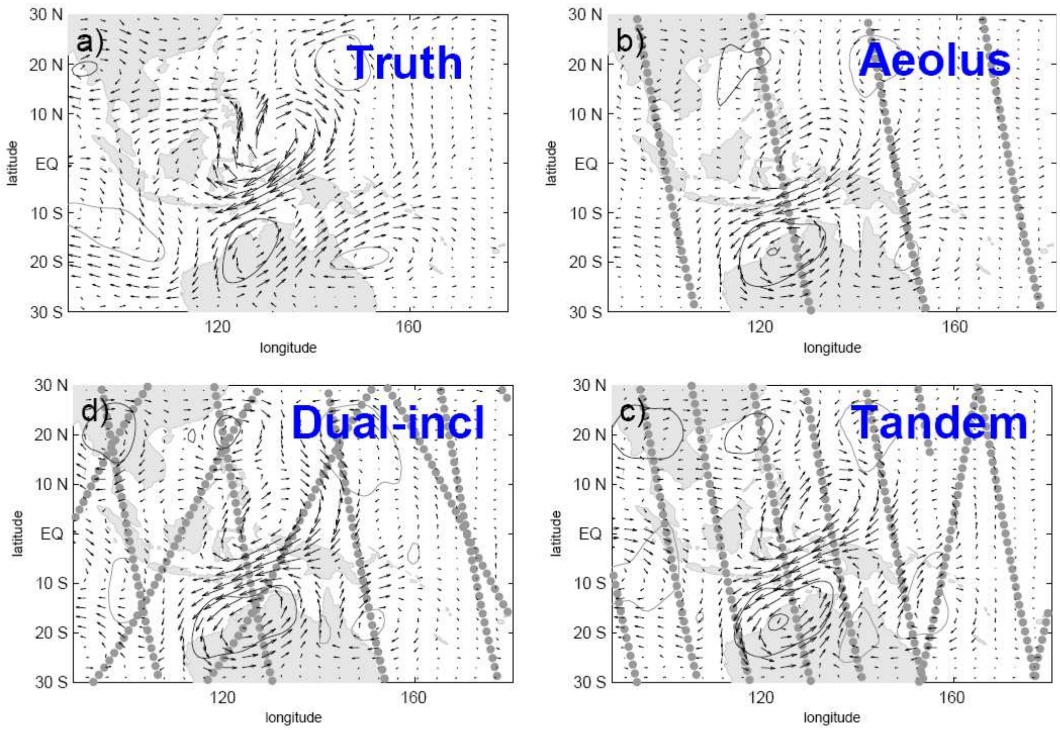

Figure 6. Impact of some PIEW follow-on scenarios on the tropical circulation (see Figure 5).

like DWLs and these simulated wind profile observations are provided to the analysis steps over 84 hours. A longer period is used, since the adjoint structures reinforce over time, gradually improving the forecast skill in the pseudo-truth run, and since the DWL impact is reinforced over time as well. We used the common extratropical storm detection criteria of wind speeds over 10 Beaufort or mean sea level pressure, PMSL, below 980 hPa. In all three experiments the ECMWF Ensemble Prediction System with 50 members was run to verify the relative occurrence of storm members in the two-day forecast. Three times more storm members occur in DWL (30%) than in noDWL (10%) over France and Gulf of Biscay. We also found that the DWL storm locations are better situated than the noDWL locations.

The PIEW scenarios were also tested in the tropics. It was verified that wind observations are fundamental to describe the circulation in the equatorial region. Wind coverage is beneficial for all scenarios and a tandem Aeolus thus clearly outperforms Aeolus (see, e.g., Figure 6). Whereas in the extratropics, the measurement perspective, i.e., zonal or meridional, is not important, in the tropics dual perspective measurements are advantageous in order to depict the meridional component of the circulation. As such, the dual perspective scenario provides the best meridional winds, whereas the dual inclination the best overall score due to the provision of uniform coverage and dual perspective. When the background error covariance specification is adapted by error, then conflicts may arise between the information provided by temperature and wind observations. Aeolus measurement may thus aid in improving the model background error specification.

In conclusion, Aeolus is expected to improve NWP analyses and forecasts in the tropics and extratropics. Aeolus improvements result mainly from uniform sampling and provide a similar relative improvement in extreme and less extreme weather cases. Increased coverage from two satellites is clearly beneficial, where single perspective (zonal) measurements appear effective in the extratropics, but in the tropics a dual-perspective DWL mission would be useful (Zagar et al., 2008). Therefore, an Aeolus follow-on is recommended with increased coverage and perspective.

5. OUTLOOK

In spring 2010 the ESA Core Explorer Atmospheric Dynamics Mission, ADM-Aeolus is due for launch. Scientific preparations will continue in the area of campaigns, Cal/Val, and the development of an End-to-End simulator, E2S, L1 and L2 wind profile processor. With respect to Aeolus performance in relation to atmospheric heterogeneities, both in terms of processing and in terms of the distribution of vertical range gates (vertical processing levels), the characteristics of the atmosphere play an important role. High-resolution radiosondes, space lidar (CALIPSO), ECMWF model data and ground based measurement data sets are collocated to yield the combined optical and dynamical properties of the atmosphere that are relevant for Aeolus. These data bases are being used for Aeolus performance simulations and for optimizing the vertical range gates and L1 and L2 processors to retrieve wind and optical properties.

The Aeolus mission will last three years. Studies have been conducted to develop user requirements for an Aeolus follow-on mission. From these studies wind profile coverage appears important rather than the measurement perspective in the extratropics, while in the tropics both the zonal and the meridional perspectives are important as well as wind profile coverage. A complement of a side- and back-looking Aeolus type instrument would fulfil the stated requirements.

Acknowledgements
We greatly acknowledge ESA for funding the PIEW, VAMP, and ground processor studies that form the basis of this manuscript. Moreover, EUMETSAT is acknowledged for funding the tropical study as briefly reported here.

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